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CONCEPTUAL DESIGN AND COST ESTIMATE: SIX-PHASE SOIL HEATING OF THE SATURATED ZONE COMPLEX 34 SITE AT CAPE CANAVERAL

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13. ABSTRACT *(Maximum 200 words)*
A conceptual design and cost estimate are described for applying Six-Phase Soil Heating (SPSH) technology at the Complex 34 Site at Cape Canaveral, which is suspected of containing DNAPL contaminants. The design uses two circular arrays of electrodes to heat the groundwater, and a soil vapor extraction system removes the resulting steam and contaminant vapors through horizontal wells and a surface plenum. Approximately 200,000 gallons of water and 650 kg of chlorinated solvents will be removed during the eight-week treatment (more if DNAPL is present). Subsurface temperature and pressure monitoring will guide operations and collect data on treatment process. The amount of solvent removed will be monitored by periodic sampling. Groundwater samples will be collected before and after treatment. The overall cost of applying the six-phase soil heating technology for this project is anticipated as $490K. The per volume cost of this treatment operation, based on a total treated soil volume of 7,000 cubic yards, is $70 per cubic yard.

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PREFACE

This report was prepared by Battelle's Pacific Northwest Division, 902 Battelle Boulevard, Richland, WA 99352, for the U.S. Environmental Protection Agency (EPA) and the Air Force Research Laboratory, Airbase and Environmental Technology Division (AFRL/MLQ), Suite 2, 139 Barnes Drive, Tyndall Air Force Base, FL 32403-5323.

This final report provides a conceptual design and estimate of full-scale costs to apply the Six-Phase Soil Heating technology at the Complex 34 Site at Cape Canaveral for the removal of various chlorinated solvents from the subsurface. The report provides a technical description of Six-Phase Soil Heating and the status of the technology; discusses the basis of design and the conceptual design; and lists an approximate schedule and costs for applying the technology.

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EXECUTIVE SUMMARY

We have completed a conceptual design and cost estimate for applying the Six-Phase Soil Heating (SPSH) technology at the Complex 34 Site at Cape Canaveral in Florida. This site is suspected of containing a dense nonaqueous phase liquid (DNAPL) contaminant consisting of various chlorinated solvents used in cleaning operations. Based on groundwater samples and stratigraphy, the DNAPL is thought to be located near the Engineering Support Building, at a depth of as much as 45 ft. At that depth, a stiff clay layer is present that will act as an aquitard to halt the DNAPL.

Our conceptual design uses two circular arrays of electrodes to heat the groundwater from a depth of 10 ft to the aquitard at 45 ft. Each array is 30 ft in diameter and heats an areal diameter of 42 ft. The two arrays are placed side by side along the contaminated wall of the Engineering Support Building. The arrays are powered by six-phase electricity at voltages to 1,100 VAC (line to neutral) and a total power of up to 1,250 kW. Power will be obtained from the local power grid at 13.2 kV.

A soil vapor extraction (SVE) system is used to remove steam and contaminant vapors created by heating. Horizontal plastic wells placed just above the water table remove most of the steam and vapors. An insulated, impermeable plenum is placed on the soil surface to ensure the vapors are captured and collected. A secondary grid of vertical wells is placed along the building wall to capture steam and vapors migrating toward the building. The secondary vertical wells constructed of metal and connected to building ground serve as an electrical grounding grid. By establishing an equipotential barrier, this grid will prevent electrical voltages from the heating arrays from entering the building structure.

We anticipate thermal treatment to be substantially completed after eight weeks. During this time, approximately 200,000 gallons of water and 650 kg of chlorinated solvents will be removed as vapors from the soil. If a DNAPL is indeed present as a

separate phase, the amount of solvent removed could be significantly greater. The contaminated vapors will flow through a condenser and be treated (prior to atmospheric release) with a thermal oxidation unit operating at a destruction efficiency greater than 95%. The water condensate will be treated using granular activated carbon to remove the contaminants and stored in tanks. We expect the stored water to be treated to a level that will enable sewer disposal.

To protect the public and operating personnel, the electrode arrays and vapor extraction wells will be located within a locked perimeter fence with appropriate postings. A surface ground grid will be placed on the soil surface and monitored continuously to detect and stop stray voltages well within the fenced exclusion area. Vapors entering and exiting the thermal oxidation system will be monitored twice weekly to ensure appropriate destruction efficiency. Finally, thermally hot surfaces (chiefly off-gas collection pipes) that exit the exclusion area will be insulated to mitigate the hazards to operating personnel and the public.

During operation, a series of subsurface temperature and pressure monitors will be used to guide operations and to collect data on treatment progress. The amount of solvent removed will also be monitored via periodic sample analysis as the primary method for determining the level of treatment. Groundwater samples will also be collected before and after treatment to assess gross treatment levels. However, the continual recharge of groundwater containing dissolved contaminant into the treated soil volume is expected to confound the groundwater sample analyses.

The overall cost of applying the six-phase soil heating technology for this project is anticipated as \$490K. This cost includes a detailed workplan and site design (\$66K), mobilization (\$26K), subsurface installations (\$53K), above-surface installations (\$48K), startup operations (\$41K), extended operations (\$89K), demobilization (\$32K), reporting (\$18K) site restoration (\$17K), energy (\$50K), and engineering and management (\$50K). The detailed workplan and site design would incorporate applied

numerical modeling to assess the relative effects of the advective and buoyant flows within and above the groundwater to guide the final electrode and soil vapor extraction system design, monitor well placement, and assist in site operation and interpretation of data. The per-volume cost of this treatment operation, based on a total treated soil volume of 7,000 cubic yards, is $70 per cubic yard. This falls within the typical range of $50 to $80 per cubic yard for the six-phase soil heating technology.

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SECTION I
INTRODUCTION

The purpose of this document is to provide a conceptual design and full-scale cost estimate for using Six Phase Soil Heating (SPSH) to treat dense non-aqueous phase liquids (DNAPL) at Cape Canaveral's Complex 34 site. This report was prepared at the request of the Air Force Research Laboratory, Airbase and Environmental Technology Division at Tyndall Air Force Base (AFB) as part of their ongoing program to identify and develop technologies for treating DNAPL in the subsurface.

Battelle is currently under contract with the Air Force Research Laboratory to conduct research and development in support of the Air Force environmental quality research and development program. SPSH is one of the technologies under development. SPSH is a patented, multi-phase electrical technique that resistively heats soil and creates an in situ source of steam to strip out contaminants, which are then captured using standard soil vapor extraction techniques.

This document comprises the conceptual design and full-scale cost-estimate for implementing SPSH at the Complex 34 site. A background discussion of SPSH is provided in Section 2.0. At the time this report was prepared, only limited site characterization data were available; therefore, several assumptions were used to establish the design basis. These are documented in Section 3.0. The site conceptual design is given in Section 4.0, and the estimated schedule and costs are given in Section 5.0.

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SECTION II
BACKGROUND

The Air Force Research Laboratory, Airbase and Environmental Technology Division at Tyndall AFB, Florida, is the focal point for environmental quality research and development. As such, it has an extensive program dedicated to developing databases, processes, and advanced technologies for the environmental aspects of the Air Force. This includes fuels and chemicals; new weapons systems and missions; readiness and operations support; hazardous, industrial, and municipal waste management; remediation, characterization, and investigation of hazardous waste sites; noise abatement; and environmental information analysis. Battelle is under contract with the Air Force Research Laboratory to conduct research and development in support of the Air Force environmental quality research and development program.

As part of the program to identify and develop technologies to treat DNAPL in the subsurface, an expert panel convened to select technologies for additional testing and development. These technologies included SPSH.

A Technical Description

SPSH is a patented, multi-phase electrical technique that uses power line frequency (60Hz) to resistively heat soil and create an in situ source of steam to strip volatile and semivolatile contaminants. The steam and volatilized contaminants from the process are captured using standard soil vapor extraction (SVE) techniques.

SPSH speeds the removal of contaminants by two primary mechanisms. First, as temperature increases, contaminant vapor pressure increases, thereby increasing the rate of contaminant extraction. Second, by heating to the boiling point, an in situ source of steam is created that strips contaminants from the soil. The steam serves two purposes. First, its physical action drives contaminants out of those portions of the soil

that tend to lock in the contaminants via capillary forces. Second, the steam acts as a carrier gas, enabling the contaminants to be swept out of the subsurface via an extraction well.

SPSH uses conventional single-phase transformers to convert standard three-phase electricity into six-phase electricity. This electrical power is then delivered throughout the soil being treated through steel pipe electrodes inserted vertically into the soil in circular arrays of six electrodes per array. Each electrode is connected to a separate transformer wire to provide it with a separate current phase. The electrodes are installed using common drilling equipment and are constructed of standard steel well materials. In addition to delivering the electrical power to the subsurface, the electrodes can also be used simultaneously as vapor extraction wells. The soil vapor, steam, and contaminants removed are sent through a condenser to separate the vapor and liquid. These waste streams are then treated using oxidation or adsorption technologies.

B Status

SPSH was originally developed for the U.S. Department of Energy (DOE) as a method to enhance the removal of volatile contaminants from low-permeability soils. In 1993, a full-scale demonstration of the technology was performed at DOE's Savannah River Site. A layer of low-permeability clay soil contaminated with perchloroethylene and trichloroethylene was heated for 25 days. During the first 8 to 10 days, the temperature of the soil region was raised to 100°C. The heating and steaming continued for the remaining 17 days. Pre- and post-test analyses indicated that more than 99% of the contaminant mass was removed.

As part of the activities supported by the Air Force Research Laboratory at Tyndall AFB, a test was performed at Dover AFB to determine whether SPSH could be used to elevate the temperature of a flowing aquifer to the boiling point. The stratigraphy at the

site consisted of layers of sand and gravel with thin clay layers and silt to a depth of 33.5 to 34 feet below ground surface (bgs) and an underlayer of dense clay containing

thin laminations of silt and fine sand. The water table was located approximately 25 ft bgs and extended to the clay layer. Groundwater flow through the saturated zone was about 0.5 ft/day.

A single six-phase array was installed to a depth of 35 ft bgs, with the actively heated zone extending from 20 to 35 ft bgs. The diameter of the electrode array was 30 ft, creating an electrically heated zone roughly 42 ft in diameter. Subsurface monitoring consisted of temperature wells, pressure wells, vapor sampling wells, and groundwater monitoring wells.

Power was applied to the array beginning on February 7, 1997. Over 12–17 days, temperatures within the saturated zone influenced by the array rose to 100°C (see Figure 2-1). In the figure, temperature Well 1 represents temperatures in the aquifer upstream of the heating array. Temperature Wells 2 and 3 represent temperatures within the heated array, and Temperature Well 4 represents temperatures immediately downstream of the heated array. These data indicate that the entire aquifer within the zone of interest was boiling.

To study the potential for DNAPL migration and to test the effectiveness of an SVE system for removing DNAPL mobilized by SPSH, two nonhazardous, low-solubility organic tracers were injected to mimic DNAPL. Pressure and temperature monitoring were used to adjust vapor extraction parameters so capture of the tracers was ensured. Vapor well monitoring indicated some migration of the tracers; however, approximately 100% of the tracer placed at the edge of the heated zone was captured, indicating that migration was relatively small. Capture of the second tracer within the heated zone was approximately 35%. The fate of the uncaptured tracer is unclear; it is possible that its recovery was missed because of gaps in the sampling data (see client's report entitled "*Applications Analysis Report: Six-Phase Soil Heating of the Saturated Zone*, Dover Air Force Base, Delaware, October 1997").

More recently, SPSH was selected for a design verification study to remove DNAPL from a contaminated saturated zone at Fort Richardson, Alaska. The site consisted

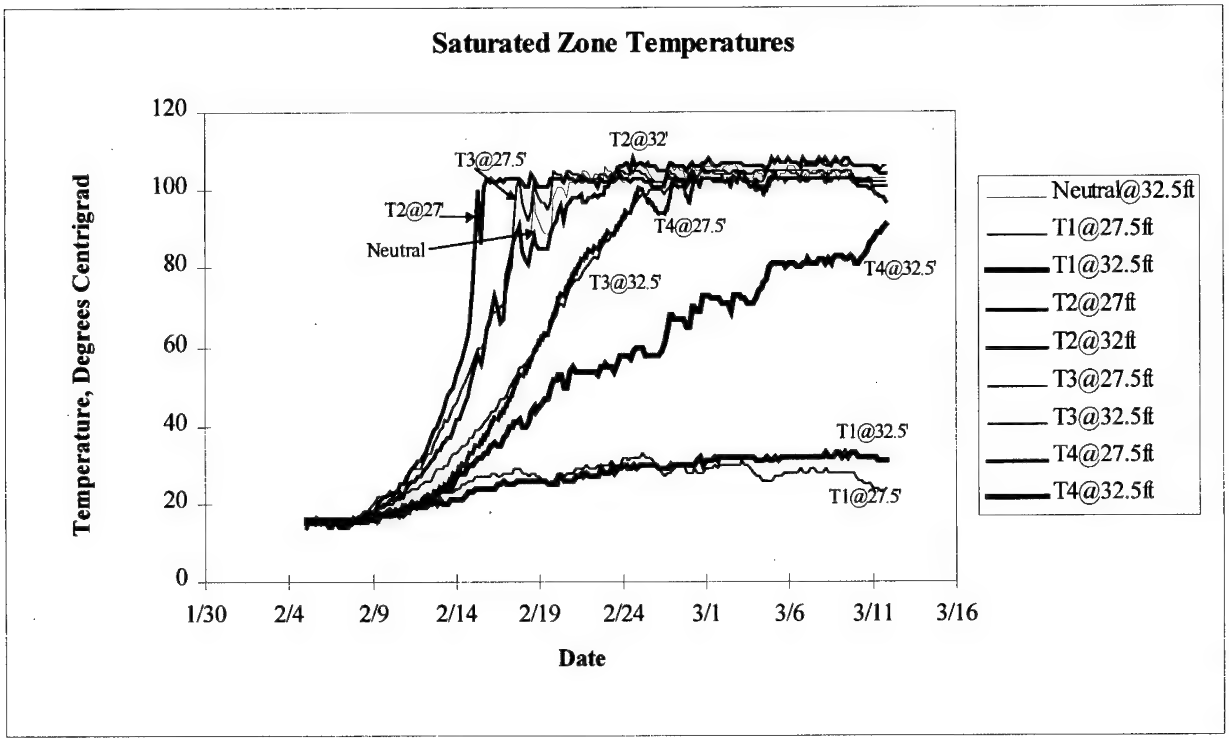

Figure 2-1. Saturated Zone Temperatures at Dover Air Force Base Demonstration

of dense, heterogeneous, low-permeability soils contaminated with various chlorinated solvents. The water table was approximately 20 ft bgs, and contamination extended to approximately 40 ft bgs. The primary contaminants were 1,1,2,2 tetrachloroethane (1,1,2,2), trichloroethylene (TCE), and perchloroethylene (PCE). The 1,1,2,2 had the highest soil concentration, ranging from less than 1 mg/kg to 1000 mg/kg. The 1,1,2,2 is especially difficult to remove because it has a relatively low Henry's law coefficient (thus tending to remain mostly in the dissolved phase) and a high boiling point (thus it is less volatile than the other compounds). Free product (i.e., DNAPL) was also found at this site.

Three arrays were operated sequentially starting in July 1997. The first two arrays were 27 ft in diameter (each heating a diameter of approximately 38 ft). The heated region was from 8 to 38 ft bgs, and the total treated volume was approximately 1,250 cubic yards per array. The third array was 40 ft in diameter (heating to a diameter of

about 55 ft) and treated approximately 2800 cubic yards. Each array region was treated for a period of six weeks.

Pre- and post-test samples were taken from four locations in the first array (two within the heated zone and two at the edge of the heated zone). Figure 2-2 shows the results for 1,1,2,2 removal from the Well 3 location within the heated zone. This location represented the region of highest contamination concentration and total contaminant mass. Overall, for the two sample locations in the heated zone, half the sampling results reported non-detect levels. Total removal, including the locations at the edge of heating, was 97% for 1,1,2,2, 94% for PCE, and 93% for TCE. Results for the second array were similar; however, only two sampling locations were used, one within the heated region and one at the edge.

The edge of the heated region of the larger, third array was not treated as effectively as the first two arrays. Unlike the first two arrays, the sample location at the edge of the predicted heated region was not heated effectively (based on temperature monitoring at that location) and showed little contaminant removal. Contaminant removal at the second sample location within the heated region, where heating was effective, was similar to the results for arrays 1 and 2. Based on the average of the two sample locations, only 50% of the contaminant mass was removed in the third array during the six-week treatment period.

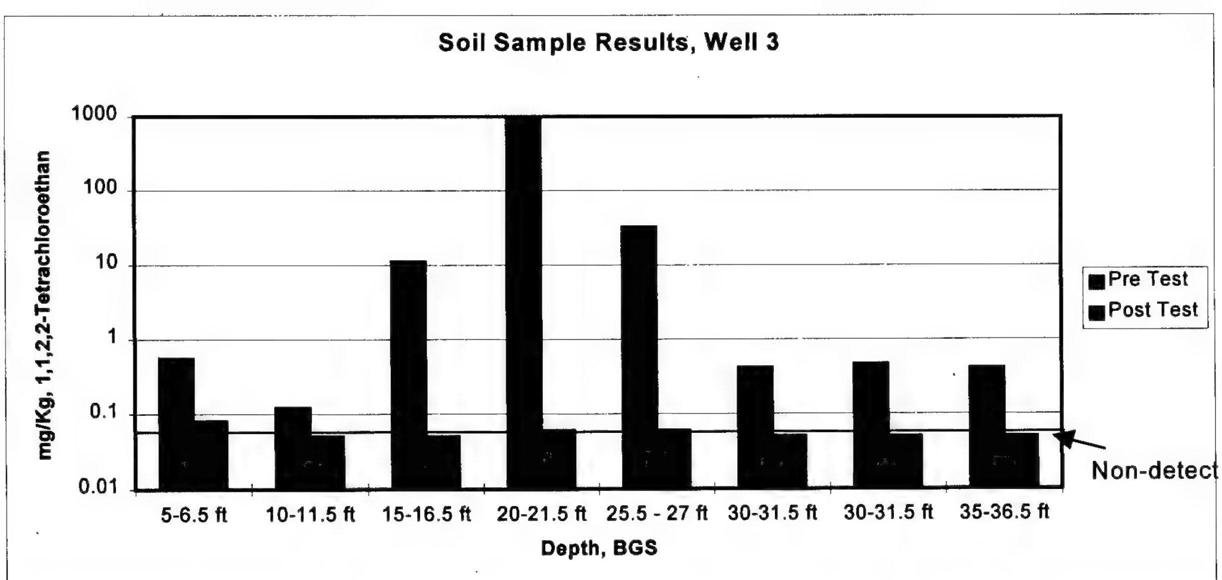

Figure 2-2. Pre- and Post Test Soil Sample Results from Fort Richardson, Alaska

The SPSH technology was applied to two additional sites in 1996 and 1997. One was a demonstration at an Air Force Reserve site, where four arrays of the SPSH process were operated simultaneously; the second was an industrial site contaminated with PCE in a fully saturated, low-permeability clay soil.

SECTION III
BASIS OF DESIGN

The basis of design requires numerous assumptions, which are discussed in the following sections.

A Site Description – List of Assumptions

The site is composed primarily of sands to a depth of about 40 ft bgs. The groundwater table is about 5 ft bgs. A layer extending from 20 to 25 ft bgs comprises shells and fine sand and exhibits a lower permeability than the sand above and below it. At about 45 ft bgs, a stiff clay layer acts as an aquitard and defines the lower extent of the intended treatment area.

The treatment area will be along the southeast line of the Engineering Support Building. During the operation of the SPSH system, access to the southeast portion of the building will be controlled as a precautionary measure. No unusual measures need to be taken for underground utilities or objects within the application area.

The high-voltage lines on the southeast side of the building can be used to provide the electrical power to operate the SPSH system. Additional low-voltage power can be obtained from the transformer on the southwest side of the building.

The contamination in the subsurface is primarily TCE (and its daughter products, such as vinyl chloride). The concentration of TCE varies throughout the area and has an upper limit of about 560 mg/L. It is also assumed that DNAPL exists in the subsurface. (The presence of DNAPL does not affect the basic design, though it may somewhat impact the off-gas treatment components and their operations.)

B Volume of Water To Be Removed During SPSH Operations

During the operation of the SPSH system, water (in the form of steam and water vapor) is removed from the subsurface. The amount of water removed is assumed to be 60% of the pore space water within the defined treatment volume at the start of the test. This is assumed to be the amount of in situ steam generation required to remove the contaminant. The treatment area is defined as 80 ft by 40 ft and the depth of treatment is 45 ft bgs. Ignoring the small amount of water in the 5-ft-deep unsaturated zone leaves a total volume of 128,000 cubic feet. Of this, 35% is water, resulting in a total of approximately 45,000 cubic feet, or about 340,000 gallons (1,300,000 L) of water. Of this, approximately 60%, or 200,000 gallons, is the expected volume of water to be removed from the subsurface over the six to eight weeks of SPSH treatment.

C Mass of Contaminant To Be Removed During SPSH Operations

To obtain an estimate of the total mass of contaminant in the treatment area, a concentration of 500 mg/L total contamination in the groundwater was assumed uniformly distributed throughout the treatment zone. Thus 1,300,000 L of water in the treatment area would contain a total of about 650 kg of contaminant. We expect that nearly all of the 650 kg will be removed during SPSH treatment of the site. It is likely that this level of contaminant is not uniformly distributed and that DNAPL is present; however, further data are not available at this time. The amount of contaminant estimated (650 kg) is significant and therefore likely represents an upper bound for the region being treated. However, actual contaminant levels could be higher if significant DNAPL is present. Of this contaminant mass, 90% will be treated in the vapor phase (by thermal oxidation), and 10% will be treated in the liquid phase (by granular activated carbon).

It is assumed that, although TCE can be flammable at some concentrations, dilution and other standard engineering controls will be adequate to handle the extracted contaminant vapors.

D Contaminant Remaining Following Treatment

Although the SPSH process will effectively remove a substantial mass of contamination from the subsurface treatment area, it must be understood that groundwater containing contamination will continue to flow into the treated area, resulting in recontamination of the area. Thus, groundwater sampling of the treated area will not be fully representative of the relative level of treatment obtained. The analyses of the extracted fluids from the treatment area and the resultant total contaminant mass removed will be more useful in assessing the relative success of the treatment process.

E Conceptual Model of Treatment

We believe that treatment of the soil column near the Engineering Service Building will proceed as follows. As electricity is applied to a nearly homogenous medium, the uppermost layer of the medium, in this case the groundwater at 10 to 20 ft bgs, begins to increase in temperature. As heating progresses, water vapor and steam are liberated near the top of the heated zone. The vapor and steam rise into the unheated soil region in the upper 10 ft of the soil formation. While much of this vapor is collected via the horizontal vapor extraction wells, a significant fraction will condense, effectively heating the uppermost 10 ft. As this uppermost region continues to heat via advection, the groundwater continues to heat with high temperatures gradually developed from the top to the bottom of the groundwater column. During this time, strong buoyant forces cause steam and contaminant vapor to rise through the soil column for collection in the horizontal wells. We anticipate that the steam will form preferential vertical paths through the soil stratigraphy, carrying the contaminant vapor with it. As the soil column heats, a groundwater circulation pattern will begin to develop, driven by buoyancy differences between hot and cold groundwater. Heated water within the treatment zone will tend to rise and flow upward in the direction of the steam movement. As a result, a return path of cold groundwater at or near ambient temperatures will migrate inward

near the bottom of the array. This groundwater circulation pattern, combined with gas/liquid buoyancy, will help contain the outward migration of volatilized solvent vapors from any DNAPL at the aquitard. We plan to conduct applied numerical modeling to assess the relative effects of the advective and buoyant flows within and above the groundwater. The modeling results would be used to help 1) establish an appropriate layer thickness (if different than 10 ft) for the unheated zone at the top of the formation, and 2) assess the benefits of a segmented electrode design that would allow switchable heating at two or more depths within the formation. For instance, it may be valuable to preferentially heat the bottom 10 ft of the soil column near the aquitard to accelerate DNAPL removal or to preheat the uppermost 10 ft of the soil column.

F Regulatory Requirements – List of Assumptions

The contaminant mass in the effluent of the thermal oxidation unit must be less than 5% of the influent contaminant mass (i.e., destruction efficiency must exceed 95%). No dispersion modeling of the thermal oxidation unit will need to be performed for the contaminants or for the hydrochloric acid (that will be generated by the oxidation of the contaminants). Field screening instruments and two laboratory samples per week will be adequate to verify the treatment efficiency of the thermal oxidation unit.

Granular activated carbon will be used to treat the condensate from the vapor extraction operations. The water discharged from the granular activated carbon canisters can be stored in tanks placed temporarily on the site. Two laboratory samples per tank will be adequate to determine whether the tank can be discharged to a sanitary sewer or similar discharge point.

No regulatory requirement limits the emplacement of the drill cuttings and other soils disturbed during site construction activities under the surface plenum for treatment. No environmental impact assessment will need to be prepared for the planned work.

No treatment will be performed nor will permits or other documents be necessary for the precipitation runoff from the surface plenum. This runoff will be routed to a storm sewer without any sampling or monitoring.

All the vertical and horizontal wells will be cut off at the surface at the conclusion of the SPSH activities. Using standard well decommissioning techniques (e.g., filling each well with grout) will fully decommission the vertical wells. No decommissioning of the horizontal wells will be required (because these wells extend only into the unsaturated zone).

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SECTION IV

Conceptual Design

The SPSH system consists of subsurface components (electrodes, extraction wells, and pressure and temperature monitoring wells) and above-surface components (including the SPSH transformer, computer control and data acquisition system, a vapor collection and treatment system, and a water treatment and storage system).

The proposed design using SPSH at Complex 34 is based on treating the highest concentration source area near the Environmental Support Building. This will require two arrays to treat an area of about 80 ft by 40 ft to a depth of 45 ft bgs. The total treatment volume is approximately 7,000 cubic yards. Figure 4-1 shows the placement of these arrays with respect to the Engineering Support Building.

Treatment operations, consisting of equipment mobilization, subsurface installation, above-surface installation, startup, operations, demobilization, site restoration, and reporting are described in the following sections.

A Subsurface Installation

The subsurface installation consists of electrodes, pressure and temperature monitoring wells, and extraction wells. All components are installed using standard techniques. Each component is discussed in more detail below.

1 Electrodes

Each array consists of six electrodes arranged in a hexagonal pattern surrounding one neutral electrode/central extraction well. The array of electrodes is 30 feet across and heats a region approximately 40 feet across. Soil between the two arrays is heated by a combination of electrical interactions between the arrays and conductive and convective heat transfer. Two additional neutrals will be placed between and outside of

he arrays, as shown in Figure 4-1.

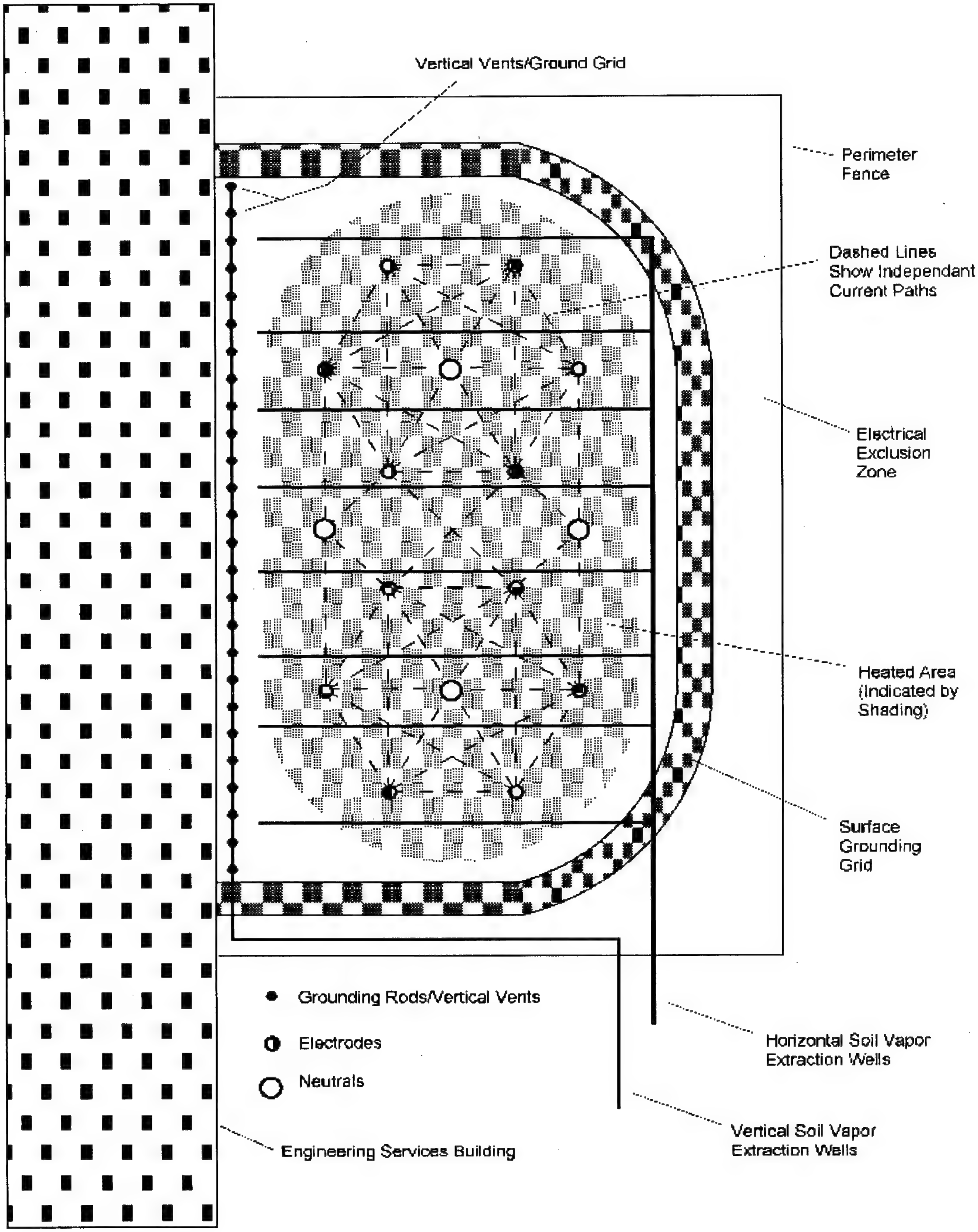

Figure 4-1
Location of Treatment Arrays

Electrodes consist of galvanized steel pipe installed in a borehole with a graphite backfill to allow good electrical contact with the soil. The electrodes will be installed using standard drilling techniques.

The electrodes will be constructed of 2-in.-diameter galvanized steel pipe 50 ft in length. The active heated region will extend from 10 to 45 ft bgs. (Lengths will be adjusted as appropriate to ensure that the installations extend to the top of the clay layer.) The upper portion of the electrode will be electrically isolated from the soil using a 4-in. diameter CPVC pipe, 10 ft in length.

The assemblies will be installed into a 12-in.-diameter hole constructed using standard drilling techniques. Drill cuttings will be placed under the surface plenum for treatment. When the assemblies are in place, the annular region between the assembly and the formation will be filled with graphite for the active heated region and sand for the electrically isolated region. The top of each well will be capped with a Portland cement grout seal (so that seal integrity is not affected by high temperature or soil drying). The electrodes and other subsurface installations are shown in Figure 4-2.

2 Monitoring Wells

Subsurface monitoring will be accomplished using temperature/groundwater monitoring wells and pressure/vapor monitoring wells. The temperature monitoring wells are designed so that they can also be used to sample groundwater. The pressure monitoring wells are designed so that they can also be used to monitor the vapor-phase concentration of contaminants. Six temperature monitoring wells and 15 pressure monitoring wells will be installed at the locations illustrated in Figure 4-3.

Temperature Monitoring Wells. Six temperature monitoring wells will be installed at locations T1 to T6 (see Figure 4-3). Each will use five thermocouples, set at 5, 15, 25, 35 and 45 ft bgs. Thermocouple bundles will be installed into the temperature monitoring wells by strapping them to the outside of a 2-in.-diameter CPVC pipe. The

thermocouple bundles will be placed at depth and then, as the auger is removed, the

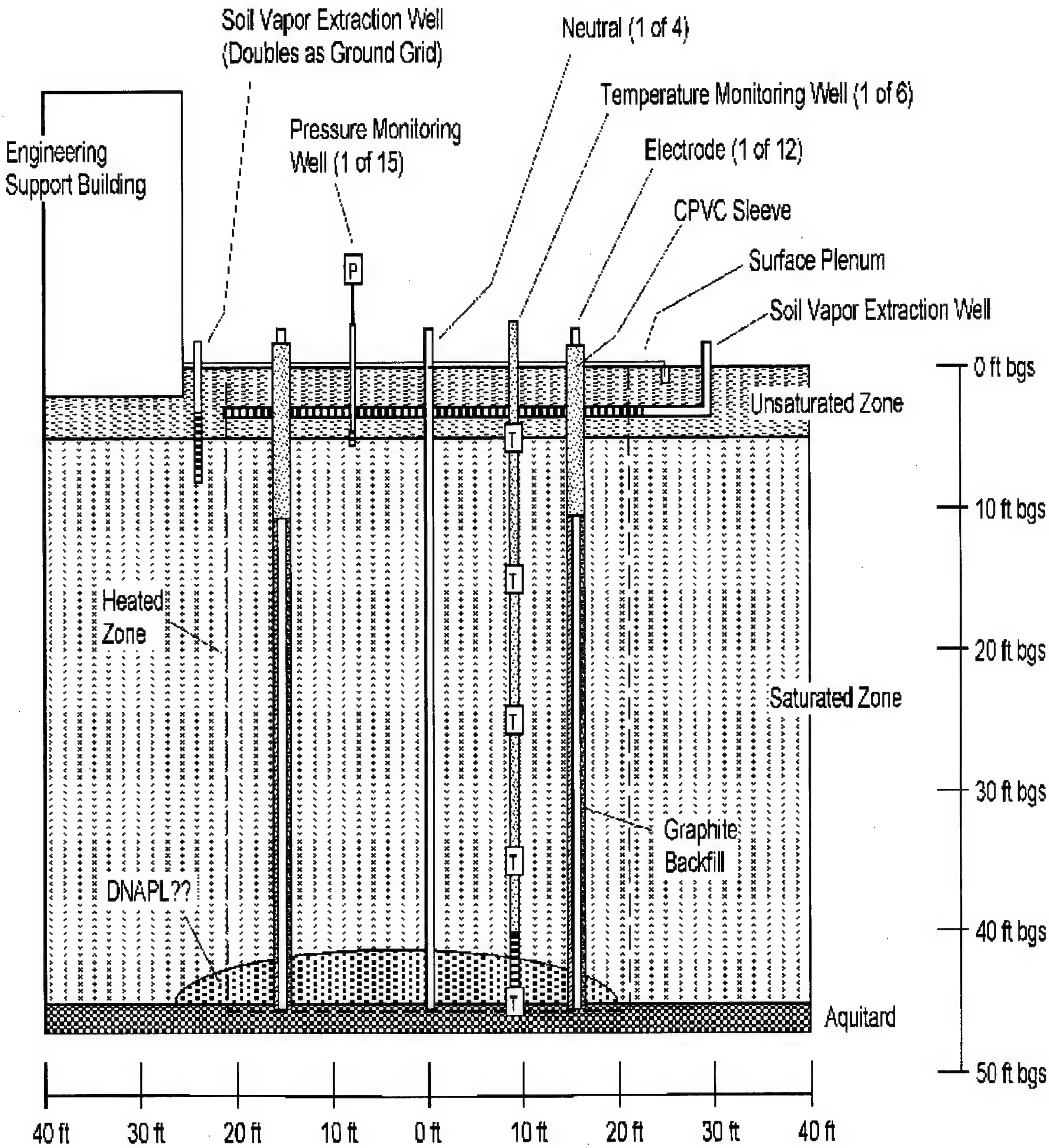

Figure 4-2
Subsurface Emplacements

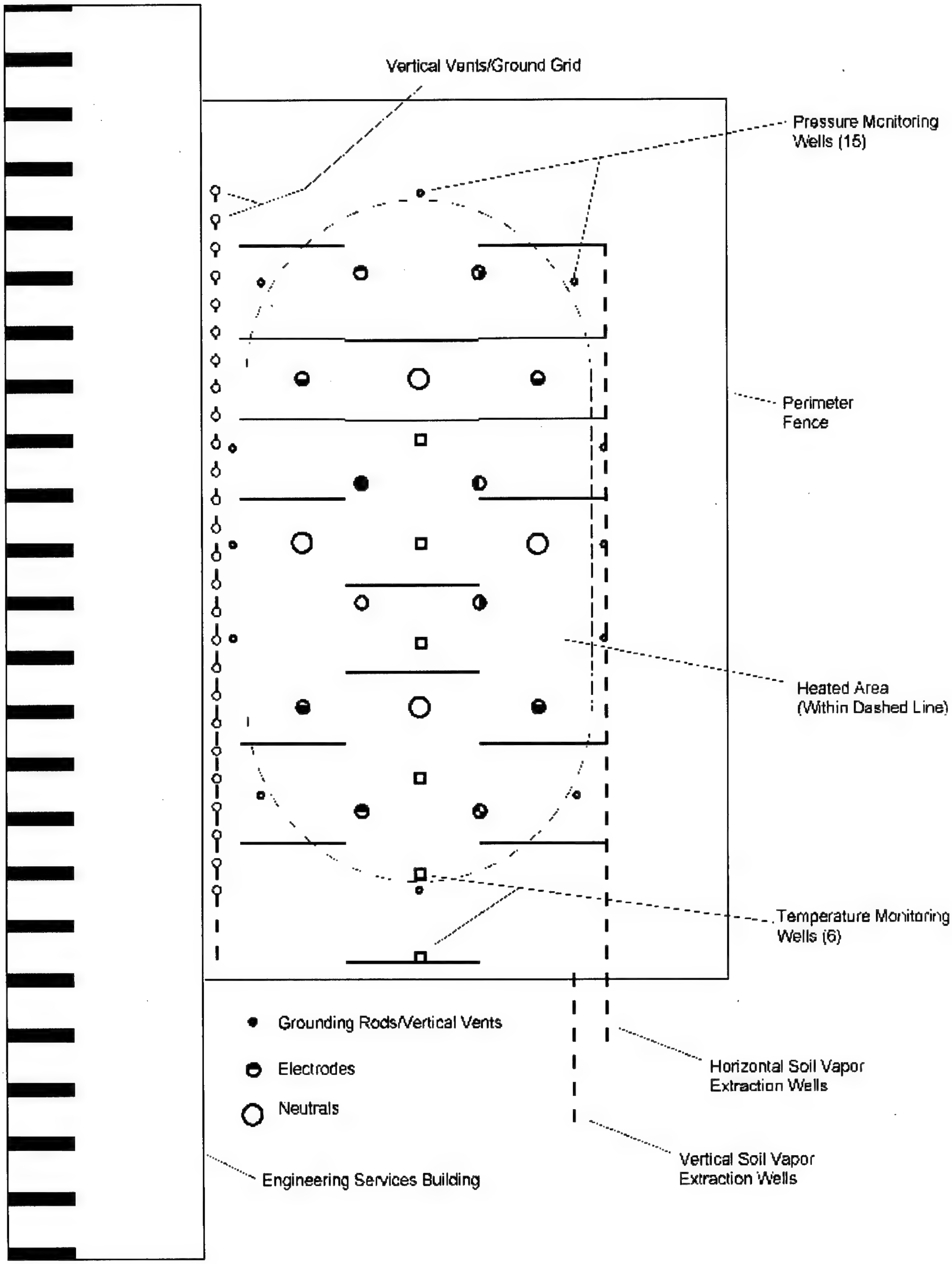

Figure 4-3
Location of Monitoring Wells

formation will collapse around the thermocouples, providing good contact with the soil. However, grout will be added as necessary to inhibit convective heat transfer between the sampling locations within the well. The 2-in. diameter CPVC pipe will be screened from 40 to 45 ft bgs to allow for groundwater sampling.

Pressure Monitoring Wells. Pressure monitoring wells will be installed at locations P1 through P15, as shown in Figure 4-3. These 0.5-in.-inner-diameter assemblies will be pushed to a depth of 5 ft by standard push techniques. The ends will be screened to keep out particulates. Computer monitoring will be used to collect data from pressure transducers placed on four of these wells. The other wells will be outfitted with manually read gauges.

3 Extraction Wells

The contaminants and steam will be extracted from the subsurface using conventional SVE techniques (including a vacuum blower connected by piping to extraction wells placed in the subsurface). The contaminants and steam extracted from the subsurface will be treated in an above-surface treatment system described in Section C.

Vapor extraction will be performed primarily using horizontal wells. These extraction wells will be placed in the unsaturated zone above the heated region. Because of the limited thickness of the unsaturated zone (approximately 5 ft), the vacuum that could be placed on a vertical extraction well would be relatively small (due to groundwater upwelling), resulting in a small radial influence and thus requiring a very large number of wells. Instead, a system of horizontal extraction wells will be installed above the heated region in trenches dug three to four ft bgs. This area will then be covered to form a plenum, which will extend the radial influence of the extraction operations, helping to ensure capture of the steam and contaminants. In addition to the horizontal wells, the pipes placed in the treatment area for the grounding grid will be slotted to

provide extraction capabilities. The extraction system is illustrated in Figures 4-1 and 4-2.

The surface plenum will consist of an impermeable membrane that is covered with insulating blankets and placed over the entire heated region. The plenum serves two purposes: 1) to reduce the short-circuiting of atmospheric air to the subsurface, thus extending radial influence of the extraction operations and resulting in more effective capture of the steam and contaminants volatilized by the heating; 2) to act as a thermal barrier, preventing excessive heat loss from the soil surface and minimizing condensation of the steam and contaminants prior to extraction from the subsurface. The edge of the surface plenum will be buried in the soil at the edge of the treatment region to help prevent short-circuiting of the atmospheric air to the subsurface. Soils from the trenching operations (for both the horizontal wells and the emplacement of the surface plenum edge) will be placed beneath the surface plenum for treatment.

B Power Supply and Control

The SPSH power supply conditions and phases electrical energy for optimum soil heating. This equipment is a trailer-mounted set of transformers controlled remotely and/or locally with a rated constant power output of 1,250 kVA at 60 hertz. The system provides six separate, simultaneous outputs with voltages adjustable from 0 to 1100 V. A panel-mounted, man-machine interface can control the power supply from the trailer (local) or through a remote computer. The power supply will be connected to a 13.2-kV electrical drop provided by Cape Canaveral from a location at the east side of the Engineering Support Building (see Figure 4-1).

Computer Control and Data Acquisition. Data are collected on a control computer running under a Windows operating system. The Intellutions FIX DMACS software will be used to collect and store temperature, power, voltage, current, and operational status data. Operations personnel can access the digital acquisition system and control computer remotely by phone line to monitor and control the heating process.

Heating Operation. The two SPSH arrays will be heated simultaneously by applying electrical voltage from the SPSH transformer. The estimated power requirement is 1,000-1,200 kW to heat the soil to 100°C over a period of approximately two weeks. Once these temperatures have been achieved, power will be maintained for an additional four to six weeks to continue to boil soil moisture and strip contaminants. Estimated total treatment time is six to eight weeks. The estimated steam generation rate is 1,400 scfm at maximum steaming conditions. This rate depends on many factors, including the applied power and heat losses to the surrounding soil and surface.

C Off-Gas and Water Treatment

Upon extraction from the subsurface, the contaminants and steam will flow through a condenser, resulting in a vapor stream and a liquid stream. Both streams will require treatment for removal of contaminants.

Most of the contaminants will be in the vapor stream, which will be treated using a thermal oxidation unit (thermox) to oxidize the contaminants prior to discharge. Although a catalytic oxidation unit (catox) could be used for this application, the short operational period of six to eight weeks and the greater ease of performance makes the use of a thermox more appropriate. The thermox will require external energy for operation, which can be supplied as electricity, natural gas, or propane, depending upon the availability of utilities at the site.

The vapor effluent of the condenser will flow directly to the thermox for treatment. The destruction efficiency of the contaminants will be greater than 95% (based on the influent concentration) and will be monitored by site personnel using standard gas sampling and analysis techniques. It is assumed that the mass of hydrochloric acid (HCl) produced during the operation of the thermox will be below the level requiring

monitoring. Permits for operation of the thermox will be obtained from the regulatory agencies and coordinated through the site.

The liquid effluent of the condenser will flow through granular activated carbon canisters (placed in series) to remove the contaminants of concern. The liquid will then be placed in holding tanks (e.g., frac tanks) brought onto the site for the temporary storage of the liquid. The liquid will then be analyzed and discharged to the sanitary sewer or other location as agreed upon with the regulatory agencies, municipalities, and the site.

D Health and Safety

This section discusses how health and safety issues affect the conceptual design and is not intended to provide the level of detail required for a workplan. The primary health and safety concerns for the site are the exposure to chemical hazards, high temperatures, and electrical shock.

During SPSH operations, volatile chemicals in the subsurface will be liberated, extracted, and treated with above-ground equipment. Potential exposure to these chemicals exists throughout the operational period, primarily through inhalation. However, the operation of the system is essentially the same as that of a typical SVE system. The chemicals will be extracted from the subsurface under a vacuum and then removed from the air and water using thermal oxidation and adsorption, which are standard industry practices. Both the system and the area will be extensively monitored during the operational period. This includes monitoring the area (including the breathing zone) and extracted fluid for contaminant concentration and monitoring the effluent from the treatment processes for chemical concentrations (including hydrochloric acid, which is a byproduct of the oxidation of the chlorinated compounds). Because of the nature of this technology, its operation is not expected to create a significant potential risk to personnel or uninvolved workers due to exposure to chemicals.

During the SPSH operation, the temperatures of the soil may reach 110°C, especially near the electrodes. The surfaces of the extraction piping may also be hot up to the condenser inlet. Hot surfaces in areas where personnel are operating will be insulated to prevent burn hazards. If personnel must enter the exclusion zone (though

access to the exclusion zone is limited to times when the power is off), proper protective equipment must be worn, including heavy-soled shoes and insulated gloves. Contact with the electrodes should be avoided.

During SPSH operation, the soil is electrified, and hazardous voltages are present within the treatment area. Exclusion-zone and site-perimeter fences are installed to prevent personnel from entering the site when power is being applied. To prevent stray voltages outside the exclusion zone, a grounding grid is installed and monitored continuously. During initial checkout of the SPSH system, electric fields are measured to ensure the grounding system is functioning properly. These safety checks include a survey of step-and-touch potential at any location that may be accessed by personnel outside the exclusion zone. Any hazardous conditions identified during this survey are immediately rectified. Again, access to the exclusion zone is limited to times when the power is off.

SECTION V
SCHEDULE AND COSTS

The activities required to remediate the Cape Canaveral Site 34 include the following:

- workplan preparation
- equipment mobilization
- subsurface installation
- above-surface installation
- startup
- operation
- demobilization and site restoration
- reporting.

The following activities were not included in costing this conceptual design:

- pre- and post-test characterization
- regulatory interface.

These activities depend on site-specific requirements and can vary significantly. However, the cost of these efforts should be similar among the technologies being evaluated. We estimate that the entire project can be completed in eight months. A typical treatment schedule is presented below.

Week 0	Begin project
Week 12	System design and workplan is complete
Week 14	Begin installation of electrodes and wells

Week 16	Begin mobilizing SPSH equipment from Richland, Washington
Week 18	Installation of the electrodes and venting wells is complete
Week 20	All installation complete. Begin safety and operational checks
Week 22	Begin heating
Week 30	Operation is complete; begin demobilization and site restoration
Week 36	Final report submitted.

Estimated costs for these activities are shown in Table 5-1. These costs are based on previous experience and were developed using specific cost quotes when possible.

Table 5-1. Estimated Costs

ACTIVITY	COST
Site Design & Workplan	$66,000
Mobilization	26,000
Subsurface Installation	53,500
Surface Installation	48,000
Start-up	40,500
Operations	89,000
Demobilization	32,500
Reporting	18,000
Site Restoration	17,000
Energy	50,000
Engineering & Management	50,000
TOTAL COSTS	$490,500